Economic Analysis

Research Paper Series

Assessing the Impact of Greenhouse Gas Emissions on Canada's Productivity Growth, 1981-1996: An Experimental Approach

by Tarek M. Harchaoui and Pierre Lasserre

No. 009

Statistics Canada   Statistique Canada

Canada

ECONOMIC ANALYSIS RESEARCH PAPER SERIES

The Economic Analysis Research Paper Series provides for the circulation of research conducted by the staff of National Accounts and Analytical Studies, visiting Fellows and academic associates. The research paper series is meant to stimulate discussion on a range of topics including the impact of the New Economy, productivity issues, firm profitability, technology usage, the effect of financing on firm growth, depreciation functions, the use of satellite accounts, savings rates, leasing, firm dynamics, hedonic estimations, diversification patterns, investment patterns, the differences in the performance of small and large, or domestic and multinational firms, and purchasing power parity estimates. Readers of the series are encouraged to contact the authors with comments, criticisms and suggestions.

The primary distribution medium for the papers is the internet. These papers can be downloaded from the internet at www.statcan.ca for free. Papers in the series are distributed to Statistics Canada Regional Offices and provincial statistical focal points.

All papers in the Economic Analysis Series go through institutional and peer review to ensure that they conform to Statistics Canada's mandate as a government statistical agency and adhere to generally accepted standards of good professional practice.

The papers in the series often include results derived from multivariate analysis or other statistical techniques. It should be recognized that the results of these analyses are subject to uncertainty in the reported estimates.

The level of uncertainty will depend on several factors: the nature of the functional form used in the multivariate analysis; the type of econometric technique employed; the appropriateness of the statistical assumptions embedded in the model or technique; the comprehensiveness of the variables included in the analysis; and the accuracy of the data that are utilized.

Any interpretation of the results that are reported in these series should recognize that empirical analysis always involves some degree of uncertainty and readers should take this into account.

Publications Review Committee
Analytical Studies Branch, Statistics Canada
24th Floor, R.H. Coats Building
Ottawa, Ontario, K1A 0T6
Telephone: (613) 951-1804

Assessing the Impact of Greenhouse Gas Emissions on Canada's Productivity Growth, 1981-1996: An Experimental Approach

by

Tarek M. Harchaoui*
Statistic Canada
Pierre Lasserre
Université du Québec à Montréal

11F0027 No. 009
ISSN: 1703-0404
ISBN: 0-662-33032-3

Micro-Economic Analysis Division
24-B R.H. Coats Building
Ottawa, K1A 0T6
Statistics Canada
Facsimile Number: (613) 951-5403

*(613) 951-9856
Email: harctar@statcan.ca

November 1, 2002

The authors' names are listed alphabetically.

The opinions expressed herein are those of the authors and do not necessarily reflect the opinions of Statistics Canada.

The comments made by John Baldwin and participants at the 7th European Workshop on Efficiency and Productivity Analysis, (Oviedo, Spain) and at the 11th annual meeting on the Canadian resource and environmental economics, Brock University, (St.-Catharines, Ontario), are acknowledged with thanks.

Aussi disponible en français

Table of Contents

Abstract

Despite the progress that has been made in the measurement of productivity, there have been few attempts to cast emissions of bad outputs within a joint-production framework. This paper does so. It proposes an experimental framework that depends critically on the shadow price estimates of emissions. These shadow price estimates result from the estimation of a cost function for each industry of the Canadian business sector. Using a detailed industry dataset that accounts for marketed output and greenhouse gases over the 1981-1996 period, our results suggest that the shadow values of greenhouse gas emissions are significantly different from zero. Our results also indicate that, under a non constant returns to scale technology, failing to account for greenhouse gas emissions understates productivity growth.

Keywords: shadow prices, greenhouse gases, productivity

Executive Summary

Productivity growth is a major source of the improvement in living standards through its positive impact on real incomes. However, the link between estimates of productivity growth and increases in real living standards cannot be accurately gauged if productivity measures do not take into account environmental effects of production. Unfortunately, estimates of productivity growth often ignore the environmental impacts of economic activity.

Ideally, estimates of productivity growth should take account of all inputs and outputs associated with a production process, including changes to the environment. In practice, productivity growth is normally estimated using techniques that only take account of inputs and outputs that are priced. Since most environmental impacts are not traded in markets, they rarely have observable prices and so tend to be ignored when estimating productivity growth.

This paper develops and applies an experimental measure of productivity growth that can incorporate environmental impacts. To do so, it estimates a shadow or implicit price of the unpriced emissions. The methodology builds on the established technique of a cost-function-based model and uses data that relate greenhouse gas emissions and industry output over the 1981-1996 period. We apply our methodology to one of the more important environmental issues facing Canada — greenhouse gas emissions, a relatively novel application.

We use our methodology to estimate partial abatement elasticities. These show the proportionate change in the private cost required to abate greenhouse gas emissions by 1 per cent, everything else held constant. Based on past relationships between costs of production and quantities of emissions, the estimated elasticities averaged -0.14, with a wide variation across industries. This reflects the fact that different industries with different technological structures have reacted differently in the past to changes to greenhouse gas emissions. An elasticity of -0.14 indicates that a 1 per cent reduction in greenhouse gas emissions requires a 0.14 per cent increase in the industry's private cost.

Greenhouse gas emissions are found to be substitutes of capital input, indicating that more capital is required to reduce greenhouse gas emissions. In contrast, energy input is a complement to greenhouse gas emissions, but the relationship between labour input and greenhouse gases is statistically not significant.

For comparison purposes, we estimated productivity growth both excluding and including greenhouse gas emissions in a non-constant returns to scale framework. Overall, our results show that ignoring greenhouse gas emissions causes the productivity growth of the Canadian business sector to be under-estimated by 21 percent on average over the 1981-1996 period.

The framework employed in this paper allows us to take into account the unpriced environmental impacts into the productivity growth estimates. The methodology provides useful insights into how estimates of productivity growth are affected by the environmental impacts of economic activity. A disadvantage is that the methodology is data intensive and technically challenging. The productivity growth estimates that the experimental approach produces depends on the shadow price of CO_2 emissions. Because it is derived from a multivariate statistical analyses, there is an inherent uncertainty in the accuracy of the shadow price. It should be recognized that the results of these analyses are therefore subject to error. The size of the error will depend on the nature of the functional forms used, the type of econometric analysis employed and the accuracy of the data that are utilized.

I. Introduction

Greenhouse gas emissions (GHG: carbon dioxide, methane, nitrous gases and chloroflurocarbons) and the prospect of global climate change has spawned a broad research program to identify, model, and determine the impact of increases on mean global temperature. There is increasing concern regarding the economic and environmental costs of the greenhouse gases effect (global warming). Various groups have called for concerted international action to reduce emissions of CO_2. In response to these calls, proposals for emissions cuts have emerged at various international conferences, notably the World Climates Conferences at Toronto (1988) and Cairo (1990).

The recognition that economic activity is contributing, through greenhouse gases, to global warming, with its attendant costs, has set in motion a substantial research effort. This has taken place primarily within the domains of climatological and physical modelling, with widespread attention being paid to the economic issues concerning climatic change only in the last decade. Early examples of economic analysis were concerned predominantly with the relative efficacy of different policy instruments for achieving given targets of emission reduction at the macroeconomic level.

A number of contributions have summarized what we have learned and what we still do not know about global warming (Panel on Policy Implications of Greenhouse Warming (1992); Cline (1992) and Nordhaus (1994)). While there are many physical, biological, and social dimensions to global warming, public policy requires information in at least four areas: a) evidence that global warming has occurred or is likely to occur in the future; b) predictions on the magnitude and timing of global warming, c) estimates of the damage from global warming, and d) estimates of the cost of taking actions to reduce global warming or to mitigate its damage. This paper falls in the latter category. Specifically it looks at the productivity effect of reducing GHG emissions by treating emissions as part of the production process.

This paper develops and applies an experimental measure of multifactor productivity growth that can incorporate unpriced environmental impacts. This method requires an estimate of the implicit or shadow price of emissions. The methodology to estimate this implicit price builds on the established technique of a cost-function model of the Canadian business sector and is applied to one of the more significant environmental issues facing Canada—greenhouse gas emissions.

Economists have tried to devise a productivity indicator that takes into account the production of bad outputs. Because multifactor productivity measures have been so closely related to changes in living standards, it is natural to ask whether net increases (i.e., after taking account of any increase in inputs) in marketed outputs are the only things that should 'count' as gains to our standard living. Pittman (1983) proposed a multilateral productivity index that includes undesirable as well as desirable outputs, valuing emissions by shadow prices. This approach represents an important step forward in productivity measurement, one that has been followed up only recently. His empirical results showed substantial differences between the conventional and the proposed extended productivity measures. More recently, the contributions of Färe and Grosskopf (1998) and Gollop and Swinand (2001) accept the notion that changes in commodities

that are not priced in markets should be considered in evaluating performance and indicate how they should be 'valued' in the productivity indexes.

Färe *et al.* (1993) have attempted to derive plant-specific shadow prices for emissions equal to the cost of the desirable output that must be foregone to reduce the undesirable output by one unit. A similar methodology has been used by Hailu and Veeman (2000) to construct multifactor productivity estimates for the pulp and paper industries. The adjusted multifactor productivity growth measures that they report are higher than the conventional.

In this paper, we develop a basis for integration and extension of the existing literature on the impact of bad outputs on economic performance, focusing in particular on their private implicit value. The private benefits to producers of using the environment as a free input take the form of higher output, or lower input costs for a given amount of production, than if producers reduced the "bad" outputs associated with production. That is, lowering emissions implies either decreasing marketed outputs (since "bad" outputs are produced jointly with "good" outputs) or increasing inputs (from the substitution of energy input or alternative waste disposal). Thus, actions requiring reduction of greenhouse gases impose private costs on the business sector.

Measuring the private shadow values of greenhouse gases and their link to the demand for other inputs and other components of the production structure requires a detailed estimable model of the production cost. This is accomplished using a rich industry-level (37 industries for 1981-1996) panel data set from the Canadian productivity accounts supplemented by data on greenhouse gases and natural capital from Statistics Canada's environment program. Experimental estimates on total capital input that combine both produced capital and natural capital were also constructed and implemented in our empirical work. Econometric implementation of the model with this data base allows estimation and statistical inference of the shadow or implicit price of greenhouse gases along with its relationship with input demand, technological substitution possibilities and productivity performance.

We find shadow values of greenhouse gases to be significant, larger for the crude petroleum and natural gas industry and increasing in magnitude over time. The results indicate that GHG are substitutes of capital input and complements to energy input. But the relationship between GHG and labour input is statistically not significant. We also find that, on average, conventional estimates of multifactor productivity underestimate productivity performance by about 21 percent over the 1981-1996 period.

The remainder of the paper is organized as follows. Section II is devoted to the theoretical framework; Section III gives details on data and econometric implementation; Section IV presents the results and their interpretation. Section V provides concluding remarks.

II. The Theoretical framework

1. Costs and Shadow Prices

Measuring the costs and benefits of greenhouse gases and associated environmental damage (emissions for short in the sequel) involves explicitly modeling the production structure, recognizing the wide variety of output (revenue) and input (cost) patterns exhibited in the data. Our industry-level data set includes information on the production of one "good" output and one associated "bad" output (emissions), and the use of four inputs.

We base our analysis on a cost-function characterization of input demand in the Canadian business sector. For empirical implementation, this cost function is augmented by industrial and temporal fixed effects to accommodate differences across industries and time periods. This detailed modeling framework allows us to explore a rich set of interactions among output production, emissions, and input demand.

More specifically, our total cost function takes the general form $G(Y,B,w,D,t)$ where Y is the output; B is the "bad" output; w is a vector of input prices (labour, L; capital, K; energy, E; other intermediate inputs, M); D is a vector of dummy variables corresponding to fixed effects for each industry; and t is a time trend. The total cost function measures the total of the expenditures made by an industry for all the inputs it pays explicitly for labour, capital, energy, materials and services. If the behavior of the firm indicates that it assigns a negative value to the bad output, such implicit cost does not enter the definition of G, although, as discussed further below, it may be inferred from it.

The variable B is included in the cost function on the realization that bad outputs are produced jointly with Y, or, conversely, that the environment is used as an input by producers when they release effluents into the atmosphere. Production of the bad output allows more marketable or good outputs Y to be produced from a given combination of paid inputs, or, alternatively, using emissions as an input allows the production of a given amount of Y at lower paid input costs.

Our approach focuses on private production costs, and emissions are treated either as an input to the production process or as an output whose negative value is not fully integrated into firms' revenues. The associated private shadow values z_B of the bad output, i.e. the (input) cost saving from allowing emissions, may be measured as the cost effects $-\frac{\partial G}{\partial B} = z_B$. This shadow value reflects the marginal amount the producer incurs as a result of a reduction in B. We expect that $z_B < 0$.

In our framework, these shadow values incorporate the past behavioral motivations underlying cost-efficient production choices, as well as technological substitution possibilities. z_B should thus be interpreted as a *private* cost to producers, since it represents the amount that expenditure on other inputs increased (at a given output level) as emissions were reduced by one unit.

By Shephard's lemma, the demand for input j is $X_j = \frac{\partial G}{\partial w_j}$ (where w_j is the market price of input j). Then the effect of a change of B on the demand for input j (a second order cost effect) measures the dependence of the input use on the ability to dispose of emissions. For example, because the bad output is often directly related to the use of energy, decreases in E would be associated with declines in B (while increases in most other inputs might be required to reduce emissions).

The shadow value of emissions: $z_B = -\frac{\partial G}{\partial B}$ is a relationship analogous to Shephard's lemma. In general, this is a function of all arguments of the $G(\cdot)$ function. It follows from Young's theorem that the impact on z_B of a change in an input price is symmetric to the effect of a change in B on the demand for X_j:

$$-\frac{\partial z_B}{\partial w_j} = \frac{\partial^2 G}{\partial B \partial w_j} = \frac{\partial^2 G}{\partial w_j \partial B} = \frac{\partial X_j}{\partial B}.$$

2. *Scale, Scope, and Various Relevant Technology Properties*

The framework also allows us to gain insights into the existence of cost subadditivity (cost savings) that arises from the production of a variety of outputs (economies of scope or diversity) or from larger scale of outputs (overall scale economies). Economies of scope, or cost complementarities, exist when joint production lowers aggregate costs. Overall scale economies (OSE), a measure of total output cost elasticity as a firm expands outputs along an output ray emanating from the origin, holding output mix constant, is defined as

$$OSE = \frac{\partial \ell nG}{\partial \ell nY} + \frac{\partial \ell nG}{\partial \ell nB} = \varepsilon_{G,Y} + \varepsilon_{G,B}.$$

If OSE is equal to (is greater than) (is less than) 1, production of this vector of output exhibits constant (decreasing) (increasing) returns to scale.

Economies of scope (ESC), a second indicator of the extent to which jointness among outputs gives rise to cost savings, can be examined through the second order cost effects

$$ESC = \frac{\partial^2 G}{\partial B \partial Y} = \frac{\partial MC_Y}{\partial B} \equiv \frac{\partial z_Y}{\partial B}.$$

The shadow value of the good output Y is its marginal cost $\frac{\partial G}{\partial Y} = z_Y$; indeed, if the industry is competitive, this should be equal to the price of the good output. Cost complementarities imply economies of scope if $ESC < 0$; diseconomies of scope are indicated by $ESC > 0$, whereas $ESC = 0$ is consistent with the existence of additive costs.

The elasticity $\varepsilon_{z_Y,B} = \frac{\partial \ell nMC_Y}{\partial \ell nB}$ measures the impact of emission reduction on marginal cost; it provides some indication of private producers' motivations to adapt output levels to exogenous (e.g. regulatory) changes in emissions. For example, under competition, to the extent that MC_Y is

increasing in Y, an increase in MC_Y resulting from emissions reduction would suggest reduced production of Y. Other market configurations can be analyzed as well.

3. *Multifactor Productivity*

The information about the production structure derived in the previous sections is required in order to measure and decompose multifactor productivity growth between overall scale economies and technical change. As is well known, multifactor productivity growth and technical change coincide only under constant returns to scale.

Total differentiating the total cost function $G(Y,B,w,D,t)$ with respect to time yields

$$\frac{dG}{dt} = \sum_{j=1}^{4} \frac{\partial G}{\partial w_j}\frac{dw_j}{dt} + \frac{\partial G}{\partial Y}\frac{dY}{dt} + \frac{\partial G}{\partial B}\frac{dB}{dt} + \frac{\partial G}{\partial t}. \tag{1}$$

Dividing $\frac{dG}{dt}$ by G, setting $\frac{\partial G}{\partial w_j} = X_j$ (Shephard's lemma) and rearranging the terms, we get

$$\dot{T} = \frac{\dot{G}}{G} - \sum_{j=1}^{4} \frac{w_j X_j}{G}\frac{\dot{w}_j}{w_j} - \dot{Q}, \tag{2}$$

where

$\frac{\dot{G}}{G} \equiv \frac{dG}{dt}\frac{1}{G}$ = the total change in the cost function,

$\dot{T} \equiv \frac{\partial G}{\partial t}\frac{1}{G}$ = the proportional shift in the cost function,

$\varepsilon_{GY} = \frac{\partial G}{\partial Y}\frac{Y}{G}$ = the cost elasticity of the good output Y,

$\varepsilon_{GB} = \frac{\partial G}{\partial B}\frac{B}{G}$ = the cost elasticity of the good output B,

and $\dot{Q}$ is the aggregate output growth rate , the sum of the good and the bad outputs growth rates weighted by their respective cost elasticity, that is

$$\dot{Q} = \varepsilon_{GY}\dot{Y} + \varepsilon_{GB}\dot{B}\cdot$$

Totally differentiating $G = \sum_{j=1}^{4} w_j X_j$ with respect to time and rearranging, yields $\sum_j \frac{w_j X_j}{G}\frac{\dot{w}_j}{w_j} = \frac{\dot{G}}{G} - \sum_j \frac{w_j X_j}{G}\frac{\dot{X}_j}{X_j}$. Substituting this equation into (2) yields

$$-\dot{T} = \varepsilon_{GY}\dot{Y} + \varepsilon_{GB}\dot{B} - \dot{I}, \tag{3}$$

where $\dot{I} = \sum_j \frac{w_j X_j}{G} \frac{\dot{X}_j}{X_j}$ is the weighted growth rate of all inputs. Following standard practice, we define the multifactor productivity growth rate as $\frac{M\dot{F}P}{MFP} = \dot{Q} - \dot{I}$ —that is, the growth of the aggregate output not accounted for by the growth of the combined inputs. Substituting, we obtain the following decomposition of the multifactor productivity growth rate

$$\frac{M\dot{F}P}{MFP} = -\dot{T} + \dot{Q}[1-(\varepsilon_{GY} + \varepsilon_{GB})]. \qquad (4)$$

This formula will be used to compute multifactor productivity and decompose this measure into its two basic factors: a) a shift in the cost function due to technical change $(-\dot{T})$; and b) a movement along the cost function due to overall scale economies $\dot{Q}[1-(\varepsilon_{GY} + \varepsilon_{GB})]$.

In the above framework, both the good and the bad output are treated as exogenous. Thus Y may be set competitively or under imperfect competition; similarly B may be affected by regulations, pressures from environment protection groups, etc.

In order to compute multifactor productivity growth and decompose it into various components discussed above, we need data on input and output growth rates, and information on the various cost elasticities involved in the above formulas. We can obtain this information from econometric estimates of the cost structure $G(\cdot)$.

III. Econometric Implementation

1. Specification of the Model

The cost function implied by the model presented in the previous section takes the general form $G = G(Y, B, w_K, w_L, w_E, w_M, D_i, t)$, where the general vector representation has been expanded to make the individual arguments of the function explicit. The vector of fixed effects D_i includes 36 industry-specific intercepts with cross effects for each input price and output quantity.

Econometric implementation of the model and construction of parametric derivative and elasticity measures first requires specifying a functional form for $G(\cdot)$. Before doing so we express all costs and prices in terms of the price of intermediate inputs, which is a way to impose homogeneity in input prices. Then we choose a translog form:

$$
\begin{aligned}
\ell n\left(\frac{G_h}{w_{sh}}\right) = {} & \beta_{oh}(D_h) + \sum_i \beta_{ih}(D_h)\ell n v_{ih} + \beta_{Yh}(D_h)\ell n Y_h + \beta_{Bh}(D_h)\ell n B_h + \beta_{th}(D_h)t \\
& + \beta_{YY}(\ell n Y_h)^2 + \beta_{BBh}(D_h)(\ell n B_h)^2 + \beta_{tt}t^2 \\
& + \sum_{i \neq j}\sum_j \beta_{ijh}(D_h)\ell n v_{ih}\ell n v_{jh} + \sum_i \beta_{iYh}(D_h)\ell n v_{ih}\ell n Y_h \\
& + \sum_i \beta_{iBh}(D_h)\ell n v_{ih}\ell n B_h + \sum_i \beta_{ith}(D_h)\ell n v_{ih}t + \beta_{YB}(D_h)\ell n Y_h \ell n B_h \\
& + \beta_{Yt}\ell n Y_h t + \beta_{Bt}\ell n B_h t.
\end{aligned} \tag{5}
$$

The subscripts i and j denote the inputs $K, L, \text{and } E$—capital, labour, and energy—while h is an industry index. v_{ih} is the relative input price, defined as $v_{ih} = \frac{w_{ih}}{w_{sh}}$, where w_{mh} is the Fisher price index of intermediate inputs.[1] Unless explicitly written as functions of industry dummies, as discussed below, the β's are constant parameters.

Interindustry differences are captured through the following parameterisation of the β's in (5):

$$
\begin{aligned}
&\beta_{oh}(D_h) = \beta_o + \textstyle\sum_h \alpha_{oh}D_h, \ \beta_{ih}(D_h) = \beta_i + \sum_h \alpha_{ih}D_h, \ \beta_{Yh}(D_h) = \beta_Y + \sum_h \alpha_{Yh}D_h, \\
&\beta_{Bh}(D_h) = \beta_B + \textstyle\sum_h \alpha_{Bh}D_h, \ \beta_{th}(D_h) = \beta_t + \sum_h \alpha_{th}D_h, \ \beta_{ijh}(D_h) = \beta_{ij} + \sum_h \alpha_{ijh}D_h, \\
&\beta_{iYh}(D_h) = \beta_{iY} + \textstyle\sum_h \alpha_{iYh}D_h, \ \beta_{iBh}(D_h) = \beta_{iB} + \sum_h \alpha_{iBh}D_h, \text{ and } \beta_{ith}(D_h) = \beta_{it} + \sum_h \alpha_{ith}D_h
\end{aligned}
$$

Differentiating (5) with respect to $\ell n v_{ih}$ and using Shephard Lemma gives the share of input $i = K, L \text{ and } E$ in total cost.

$$
\omega_{ih} = \beta_i + \sum_i \beta_{ih}(D_h)\ell n v_{ih} + \sum_i \beta_{iYh}(D_h)\ell n Y_h + \sum_i \beta_{iKh}(D_h)\ell n B_h + \beta_{ith}(D_h)t \tag{6}
$$

where $\omega_{ih} = \frac{w_{ih} \cdot x_{ih}}{G_h}$. The share of the material and service inputs is calculated as $\omega_{mh} = 1 - \sum_i \omega_{ih}$, since there are only $n-1$ independent equations in the model.

The system of equations (5), along with its associated share equations, (6) should satisfy the usual regularity conditions. In particular, for the cost function to be concave in input prices, its Hessian matrix $\left[\frac{\partial G}{\partial w_i \partial w_j}\right]_{ij}$ of second-order derivatives with respect to variable input prices should be negative semidefinite. In addition, the cost function should be nondecreasing in output. Linear homogeneity in prices is imposed by construction but can be tested by introducing the price of intermediate inputs into each share equation, and adding terms in the cost equation in such a way that the augmented share equations can still be obtained from the cost equation by partial differentiation as indicated.

[1] The Fisher price indices of material and services were aggregated using the share of materials and services in the total cost of these two intermediate inputs.

We also assume that the error terms attached to the above equations are optimizing errors and are jointly distributed with zero expected value, and with a positive definite symmetric covariance matrix.

2. *The Data and Trend Analysis*

A) Methodology

The model detailed in the previous section is estimated using data for 37 two-digit industries of the Canadian business sector during the period 1981 to 1996 (see Table 1 for the list of industries).[2]

The data set is based on an extended version of the KLEMS database developed on an experimental basis to support research themes on productivity and environmental issues. The Environmental KLEMS (E-KLEMS) database contains information, at the industry level from 1981 onwards, on the value of output, the cost of primary and intermediate inputs and Fisher chained volume and price indexes of output and inputs. These variables are supplemented with a set of environmental variables on waste (greenhouse gases and other pollutants) and natural inputs such as natural reserves assets and water use developed by Statistics Canada's Environmental Accounts (Statistics Canada 1997).

The development of the E-KLEMS database is intended to help address issues on eco-efficiency, a measure of the extent to which the economic activity makes use efficiently of the environment as a free input. Economic activity has a complex relationship with the environment. It provides the raw materials for the production of goods and services that support our living standard, but it also causes damage to the environment through the activities of businesses. The conventional productivity framework is sometimes criticized for including the value of goods and services produced and the income generated through the use of environmental assets, but not reflecting the economic cost of depleting those assets or the damage that arises from economic activity.

There are various features of the E-KLEMS database:

First, E-KLEMS records the value of environmental assets that are defined as being within the scope of the system of national accounts-known as the asset boundary. For an asset to be included within the asset boundary of the national accounts it must have an identifiable owner, and the owner must be able to derive an economic benefit from the use of the asset. Assets included are those termed economic environmental assets such as subsoil assets, land, forests, water that are under the control of an economic agent (often the government).

---

[2] We only retained the industries for which real output is reasonably accurately measured. Finance and real estate, insurance, amusement and recreational service, accommodation and food services, health and social service, business service, personal and household service and educational service have been excluded.

Table 1. Industries of the Business Sector

	Industries
1	Agricultural and related services
2	Fishing and tapping
3	Logging and forestry
4	Mining
5	Crude petroleum and natural gas
6	Quarry and sand pit
7	Services incidental to mineral extraction
8	Food
9	Beverage
10	Tobacco
11	Rubber products
12	Plastic products
13	Leather and allied products
14	Primary textile
15	Textile products
16	Clothing
17	Wood
18	Furniture and fixture
19	Paper and allied products
20	Printing and publishing
21	Primary metal
22	Fabricated metal products
23	Machinery
24	Transportation equipment
25	Electrical and electronic equipment
26	Non-metallic mineral products
27	Refined petroleum products
28	Chemical industries
29	Other manufacturing
30	Construction
31	Transportation industries
32	Pipeline transport
33	Storage and warehousing
34	Communication
35	Other utility
36	Wholesale trade
37	Retail trade

Second, the environmental data appended to the conventional KLEMS database are generally measured in physical terms. This is the case for greenhouse gases, the bad output retained in the present study, and for water use and water discharge exploited in a different study (see Dachraoui and Harchaoui, in process). While the value of greenhouse gas emissions is derived implicitly using estimates of shadow prices devised econometrically in this study, for the subsoil assets, the E-KLEMS makes use of the value of sub soil assets along with the value of the resource rent, both of which have been developed by Statistics Canada's Environmental Accounts. The resource rent is the value of the capital services provided by a natural asset. It is calculated as the unit value of the output of the natural resource production (e.g. oil and gas) net of the unit cost (which includes cost of primary and intermediate inputs). The resource rent in each period is then discounted to derive the net present value of the natural asset.

The methodology used in the Canadian Productivity Accounts to construct capital input has been amended on an experimental basis to include natural capital as part of the domain of definition of capital input. We used the capital stock estimates in current prices for twenty two produced assets and two non produced assets, land and natural reserves stocks, along with their respective user cost.

The estimates of the extended capital input are adjusted for compositional changes. In order to perform this adjustment, the rental price of these twenty four types of capital are needed. Because the rental price is not directly observable, we derive it implicitly on the basis of the available information on capital compensation, the value of capital stock assets, capital gains, the tax parameters such as the corporate income tax and investment tax credits, the depreciation rate of produced capital stock and the depletion rate of natural stock. The internal rate of return, calculated residually, ensures the consistency between capital compensation and the cost of capital of all produced and nonproduced assets. Over the 1981-1996 period, the effect of changes in total capital composition, measured as the difference between the growth rate of total capital input and the growth rate of total capital stock, grew at an average rate of 1.1 percent.

The E-KLEMS database also provides hours worked by industry. Household survey data are used to disaggregate total hours into hours worked by different types of workers classified by demographic variables such as sex, age, and education. Assuming that workers are paid proportionately to the value of their marginal products, Gu *et al.* (2002) calculate labour input as a weighted sum of hours worked by different types of workers, weighted by relative wage rates. Annual growth in the labour input for the business sector as a whole from 1981-1996 averaged 2.1 percent; hours grew an average 1.3 percent per year; and labour composition increased an average of 0.8 percent.

B) Trend Analysis of the Data

We present certain selective descriptive statistics on the cost and prices of the 37 industries in our data. In Table 2, we provide the average levels of total cost and average annual growth rates of real output and greenhouse gases, prices of real inputs and cost shares for the period 1981-1996 for the 37 industries.

As is clear from the descriptive statistics, the size of the industries, measured by total cost or gross nominal output, varies considerably. Trade, construction, transportation equipment, food and transportation are among the largest industries in the business sector defined in this paper. Other industries such as mining, tobacco, furniture and fixtures, and leather and allied products are relatively small.

	C	ω_K	ω_L	ω_M	$\dot{K}$	$\dot{L}$	$\dot{M}$	$\dot{Y}$	$\dot{B}$	$\dot{w}_K$	$\dot{w}_L$	$\dot{w}_M$
Agricultural and related service	27.5	0.171	0.226	0.548	-4.05	-0.48	2.07	2.22	-0.26	4.76	4.54	2.04
Fishing and trapping	1.6	0.347	0.244	0.331	-2.75	0.73	4.76	0.66	0.49	4.82	8.52	3.19
Logging and forestry	8.1	0.137	0.319	0.511	-3.49	-0.28	4.87	2.87	5.83	14.58	4.47	3.08
Mining	11.7	0.356	0.256	0.318	-2.13	-2.10	1.17	1.41	-0.53	3.56	4.37	2.35
Crude petroleum and natural gas	22.5	0.674	0.092	0.212	0.11	1.21	8.08	3.89	4.26	0.76	6.01	2.86
Quarry and sand pit	1.1	0.268	0.280	0.379	0.09	0.01	2.07	2.12	2.47	5.36	5.49	2.80
Services incidental to mineral extraction	4.3	0.170	0.353	0.423	0.50	1.62	1.74	0.89	-3.38	-1.35	4.35	2.58
Food	38.4	0.117	0.151	0.718	1.15	-0.16	1.28	1.13	0.38	5.99	4.20	2.08
Beverage	5.8	0.259	0.208	0.520	-0.91	-2.33	1.13	0.41	-2.85	6.41	5.55	3.00
Tobacco products	1.9	0.294	0.150	0.552	-1.36	-5.08	-0.47	-1.64	-1.96	11.89	7.92	3.90
Rubber products	3.1	0.090	0.323	0.568	0.86	-0.55	2.58	3.42	-1.20	12.57	4.87	2.40
Plastic products	5.5	0.139	0.237	0.603	4.93	3.63	5.46	5.24	2.84	5.49	4.80	2.12
Leather and allied products	1.2	0.101	0.317	0.573	-1.35	-5.72	-4.63	-4.81	-4.06	-3.85	4.27	3.13
Primary textile	3.0	0.144	0.240	0.588	-0.38	-3.45	-0.10	0.35	-1.97	5.38	5.18	1.49
Textile products	3.0	0.108	0.256	0.618	-0.09	-1.28	0.68	0.26	5.45	2.50	4.63	2.05
Clothing	6.1	0.116	0.315	0.563	1.53	-2.22	-0.18	-0.25	-2.04	3.37	3.77	2.21
Wood	15.0	0.087	0.264	0.625	0.98	0.76	3.71	3.30	3.96	14.08	4.07	3.71
Furniture and fixture	4.0	0.112	0.319	0.557	1.74	0.75	1.95	1.74	2.92	5.21	3.62	3.18
Paper and allied products	22.6	0.130	0.224	0.572	3.73	-1.43	2.46	1.84	-0.17	3.16	5.43	2.66
Printing, publishing and allied	11.7	0.15	0.358	0.459	3.80	1.25	1.78	0.64	3.15	2.79	4.53	3.65
Primary metal	23.3	0.073	0.209	0.642	0.21	-2.76	2.17	2.06	-0.61	6.15	5.73	1.74
Fabricated metal products	16.5	0.118	0.291	0.578	-0.86	0.30	0.80	0.93	2.17	5.51	4.14	2.38
Machinery (except electrical mach)	9.9	0.138	0.292	0.560	1.59	0.14	2.12	1.57	0.35	3.88	4.42	2.90
Transportation equipment	53.1	0.080	0.175	0.738	2.33	1.20	6.28	6.00	2.00	13.90	5.30	3.04
Electrical and electronic products	18.9	0.126	0.259	0.606	3.03	-1.26	8.93	6.94	-2.26	1.03	5.05	0.17
Non-metallic mineral products	6.6	0.168	0.267	0.504	-3.23	-1.24	0.55	0.13	0.62	9.16	4.04	2.63
Refined petroleum and coal products	18.5	0.025	0.047	0.899	-1.98	-4.40	-0.31	-0.04	1.49	8.98	5.07	0.25
Chemical and chemical products	22.2	0.199	0.163	0.575	1.14	-0.27	1.37	2.21	0.51	7.90	4.97	2.37
Other manufacturing	6.7	0.131	0.284	0.576	3.81	0.42	0.98	1.29	0.07	3.25	4.18	1.91
Construction	83.0	0.088	0.328	0.571	2.97	0.34	0.45	0.08	-0.43	-2.70	2.91	2.92
Transportation	38.6	0.139	0.363	0.390	1.78	0.34	2.84	2.51	2.49	3.44	3.64	2.88
Pipeline transport	3.1	0.689	0.121	0.122	3.37	0.91	6.21	5.64	8.92	3.45	6.09	2.75
Storage and warehousing	1.2	0.207	0.460	0.295	0.51	1.04	2.55	1.60	1.83	1.16	4.06	3.34
Communication	22.3	0.344	0.384	0.262	2.99	1.22	6.66	4.93	6.60	3.73	3.69	2.88
Other utility	23.2	0.596	0.197	0.131	2.40	1.40	7.76	2.68	2.22	5.24	4.49	2.26
Wholesale trade	41.7	0.184	0.491	0.293	4.16	1.73	5.96	4.86	2.64	2.51	4.80	3.18
Retail trade	48.5	0.132	0.546	0.285	3.65	1.31	4.20	2.60	1.18	0.32	3.57	3.40
Business Sector	**635.2**	**0.201**	**0.270**	**0.494**	**1.673**	**0.122**	**3.319**	**2.499**	**1.9**	**4.329**	**4.394**	**2.606**

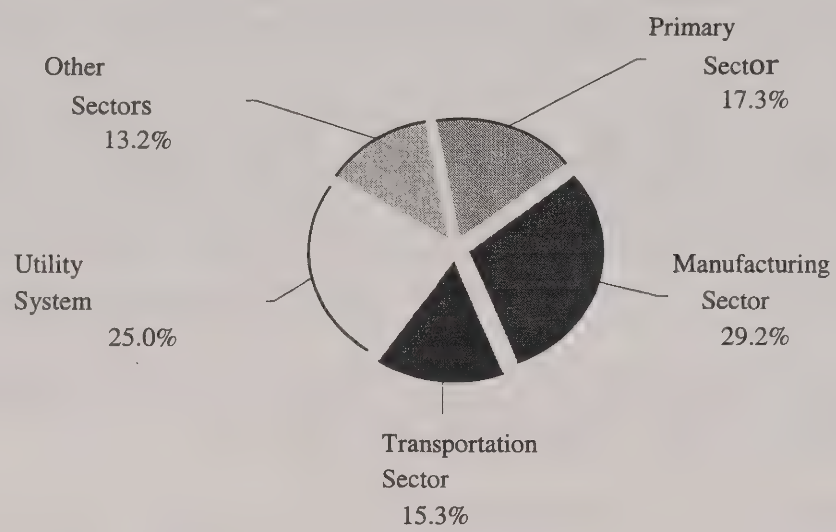
C = average total cost ($ millions); ω_K = capital compensation share; ω_L = labour compensation share; ω_M = share of intermediate expenditures; $\dot{Y}$ = gross output average annual growth rate; $\dot{K}$ = capital services average annual growth rate; $\dot{L}$ = average annual growth rate of hours adjusted for labour composition; $\dot{M}$ = average annual growth rate of intermediate inputs; $\dot{w}_i$ = average annual growth of the price of the input i (capital, labour and intermediate inputs). The chain Fisher index, where the weights are defined in terms of cost share, was used to construct the business sector figures.

In addition, factor cost shares vary considerably among the 37 industries. For example, labour compensations's share ranges from a low of about 0.09 in crude petroleum and natural gas to a high of 0.55 in retail trade. Capital compensation's share of total cost also varies considerably across industries, ranging from 0.09 in construction to 0.67 in crude petroleum and natural gas. Generally, capital compensation's share of total cost, with a few exceptions (most notably mining, crude petroleum and natural gas, fishing and trapping, chemical, pipeline transport, other utility, beverage and tobacco) is less than labour compensation's share. Intermediate inputs on the other hand, have the largest share in total cost in almost all industries, ranging from 0.12 in pipeline transport to 0.90 in refined petroleum and coal products.

Output grew at 2.5 percent over the 1981-1996 period. The rates of growth of output and inputs shown in Table 1 also vary among industries over the period 1981-1996. In leather and allied products, tobacco, clothing and refined petroleum products, the growth of output was negative. Other industries such as services incidental to mining, fishing and trapping, primary textile, textile products, printing and publishing, etc., show a lacklustre growth of output. A number of industries experienced output growth rates ranging between 1 percent to over 2.5 percent. Some industries in manufacturing and service sectors experienced impressive gains in output; the growth rates for these industries ranged from approximately 3.4 percent in rubber products to about 6.9 percent in electric and electronic products. The diversity in the growth pattern of output and inputs across industries suggests that different industries have experienced different changes in their input mix and output and productivity growth. Similar patterns of negative, small and rapid growth rates are visible in the growth rates of labour, capital and intermediate inputs. The growth rates of output price and input prices with few exceptions were generally positive but varied considerably across industries.

During the 1981-1996 period, the business sector's greenhouse gases experienced a 1.9 percent average annual growth, compared with 2.5 percent for output. Over this period, primary sector industries, manufacturing, utility and transportation were the largest producers of greenhouse gas emissions. In 1996, the generation of greenhouse gases by these four sectors accounted for 86.8 percent of the business sector total emissions, unchanged from 1981 (Figure 1).

Figure 1. Canadian Business Carbon Dioxide Emissions, 1996



Greenhouse gases annual growth rates over the 1981-1996 period also display a great deal of variation across industries. About 30 percent of all industries posted a decline in greenhouse gas emissions during this period. This includes mostly manufacturing industries such as beverage and clothing but also primary industries such as agriculture, mining and services incidental to mining which account for reasonably high contribution within the primary sector. Greenhouse gases experienced rapid growth in industries such as crude petroleum and natural gas, utility, transportation, refined petroleum and coal products. But in the majority of industries, the ratio of good output to greenhouse gases grew rapidly, which is a form of efficiency gain.

The substantial diversity in the growth of output greenhouse gases and the structure of costs among the industries over the period 1981-1996 provides a rich body of data to test econometrically the impact of different variables on the growth of output and productivity. The diversity pattern noted here implies that the response of various industries to changes in variables such as greenhouse gases or output are likely to be very diverse. Therefore, we expect the estimated elasticities, the shadow price of greenhouse gases and multifactor productivity growth rates calculated for different industries using the parameter estimates of our econometric model to vary across industries. These inter-industry variations motivate the use of a specification that captures industry idiosyncrasies.

3. Estimation

The estimation was carried out for 37 industries of the Canadian business sector for the period 1981-1996. These industries cover the mineral sector, the manufacturing sector, the non-financial services sector and utility industries. In addition to estimates for the 37 industries listed in Table 1, we also derived an estimate for these entire sectors by aggregating data across industries using Fisher indices.

The system of equations used to estimate the parameters required by our measurement framework consists of the cost function (5); and the share equations for $i = K, L$ and E given by (6). The share equation of intermediate inputs is obtained residually from the constraint that cost shares must sum to one. We have pooled time-series cross section data for 37 two-digit industries of the Canadian business sector for the period 1981-1996 to estimate the model. Estimating the model as a pooled system not only adds flexibility to the model (additional degrees of freedom) but also imposes cross-equation restrictions to allow a fully integrated cost structure model, facilitating more efficient estimates. Seemingly unrelated regressions techniques were used for estimation, since the equations share common parameters.

This equation system was estimated by non-linear seemingly unrelated (SUR) systems procedures instead of instrumental variables (IV), which is often used to take into account potential output endogeneity or errors in variables. However, we indirectly use the IV technique. The instrumental variables technique usually relies on lagged exogeneous variables as instruments. Our correction for first-order autoregressive disturbances makes use of lagged values of exogenous variables as instruments. Therefore, the correction for autocorrelation of residuals turns out to rely implicitly on the IV technique.

Adaptations were made to accommodate potential unknown sources of heteroskedasticity. Changing the input demand equations to input/output measures to reduce variations in scale across industries and time did not affect the estimates substantially. The results reported below are based on the unmodified system, using White's heteroskedastic-consistent covariance matrix to generate standard errors.

Durbin-Watson tests indicated that autocorrelated errors were present in the cost and input demand equations. Therefore, the lagged dependent variable was incorporated into the cost equation giving the form $G_t = \alpha + \beta X_t + \rho G_{t-1} + u_t$ which in turn implies, after suitable substitutions, the following form $G_t = \alpha(1+\rho) + \beta(X_t + \rho X_{t-1}) + (u_t + \rho u_t)$ where X_t refers to the vector of right-hand variables in (5), α and β refer to the corresponding parameters, and ρ is the coefficient of autocorrelation.

IV. Empirical Results

The estimated parameters and their standard errors as well as the parameter estimates for industry dummies are shown in Table 3. Although in a model this complex, the individual parameter estimates have limited interpretation, the overall statistical significance of the parameters is notable. Most industry dummies are significant; so is the estimate of ρ. The R^2s, reported in Table 3, indicate excellent "fits" for the estimated equations—all being higher than 0.95. The results also indicate that the model is well estimated. The square of the correlation coefficients between the actual and predicted values is high, and the standard errors of each equation are small. In addition, all the required regularity conditions are satisfied at each point in the sample. The coefficients of the model are statistically significant and have the correct sign.

1. Specification and Hypothesis Tests

The results of the hypothesis tests using log-likelihood ratios are shown in Table 4. The results of the hypothesis tests using log-likelihood ratios decisively reject the joint hypothesis that the dummy industry coefficients are zero (first row), indicating that strong interindustry differences are present in the cost structure of the industries under consideration. The hypothesis that the coefficients of the bad output are zero in the total cost function (5) is decisively rejected (second row). Also, the hypothesis that the cost function is homogeneous of degree one in the input prices is not rejected.

Similarly, the hypothesis that firms do not produce a joint product $\varepsilon_{GB} = 0$, that there is no technical change prevail, $\varepsilon_{Gt} = 0$, and the industries operate under overall constant returns to scale $\varepsilon_{GY} + \varepsilon_{GB} = 1$ were separately tested. In each case, the test consists in obtaining a vector of estimated parameters $\tilde{\Theta}$ from the four equation system (5)-(6) plus the additional restriction to be tested. If $\hat{\Theta}$ is the vector of unrestricted estimated parameters, then the quadratic form

$$M = (\hat{\Theta} - \tilde{\Theta})' \{Cov(\hat{\Theta}) - Cov(\tilde{\Theta})\}^{-1} (\hat{\Theta} - \tilde{\Theta}),$$

is asymptotically chi squared with degrees of freedom equal to the number parameters of the imposed restriction. Each of the first two hypotheses was rejected, but the assumption of constant ray scale economies was not rejected ($M = 210 > \chi^2_{95;.001} = 134; M = 157 > \chi^2_{95;.001} = 134$, $M = 108 > \chi^2_{95;.001} = 114$ respectively).

Table 3. Parameter Estimates of Cost Structure (Sample Period 1981-1996)

Parameter	Estimate	Standard Error	Parameter	Estimate	Standard Error
B_0	1.79844	2.22285	$\alpha_{K,14}$	-0.30771	0.241422
$\alpha_{0,1}$			$\alpha_{K,15}$	-0.3605	0.204562
$\alpha_{0,2}$	1.68764	1.71969	$\alpha_{K,16}$	-0.35499	0.200541
$\alpha_{0,3}$	1.19111	1.63142	$\alpha_{K,17}$	-0.39906	0.1789
$\alpha_{0,4}$	-0.03073	1.65079	$\alpha_{K,18}$	-0.14448	0.197741
$\alpha_{0,5}$	4.09267	1.66929	$\alpha_{K,19}$	-0.13982	0.182936
$\alpha_{0,6}$	1.94153	1.59738	$\alpha_{K,20}$	6.46E-04	0.184312
$\alpha_{0,7}$	0.942586	1.69085	$\alpha_{K,21}$	-0.38251	0.200502
$\alpha_{0,8}$	1.76937	2.4728	$\alpha_{K,22}$	-0.23782	0.196125
$\alpha_{0,9}$	1.22212	2.12094	$\alpha_{K,23}$	-0.28218	0.185983
$\alpha_{0,10}$	1.29155	1.73653	$\alpha_{K,24}$	-0.48356	0.183295
$\alpha_{0,11}$	2.6929	1.69556	$\alpha_{K,25}$	-0.18819	0.218136
$\alpha_{0,12}$	2.06508	1.58799	$\alpha_{K,26}$	-0.17009	0.178373
$\alpha_{0,13}$	-1.38548	1.7953	$\alpha_{K,27}$	-0.20937	0.188203
$\alpha_{0,14}$	1.75288	1.92197	$\alpha_{K,28}$	-0.48084	0.236293
$\alpha_{0,15}$	1.52073	1.62896	$\alpha_{K,29}$	-0.27161	0.177563
$\alpha_{0,16}$	2.22914	1.77913	$\alpha_{K,30}$	-0.23059	0.183778
$\alpha_{0,17}$	1.1383	1.62589	$\alpha_{K,31}$	-0.60302	0.282178
$\alpha_{0,18}$	0.976801	1.62156	$\alpha_{K,32}$	0.129868	0.201813
$\alpha_{0,19}$	0.183455	1.63877	$\alpha_{K,33}$	1.24E-03	0.223328
$\alpha_{0,20}$	1.08851	1.7916	$\alpha_{K,34}$	-0.55209	0.229791
$\alpha_{0,21}$	1.93164	1.77657	$\alpha_{K,35}$	0.068963	0.478113
$\alpha_{0,22}$	1.70117	1.67682	$\alpha_{K,36}$	-0.44587	0.213077
$\alpha_{0,23}$	0.8495	1.64661	$\alpha_{K,37}$	-0.40323	0.193961
$\alpha_{0,24}$	3.27164	1.63606			
$\alpha_{0,25}$	2.26088	1.6426	β_L	0.36534	0.238352
$\alpha_{0,26}$	-0.03795	1.69182	$\alpha_{L,1}$		
$\alpha_{0,27}$	1.76675	2.14642	$\alpha_{L,2}$	0.37586	0.238447
$\alpha_{0,28}$	2.74055	1.92493	$\alpha_{L,3}$	0.847295	0.281046
$\alpha_{0,29}$	1.02683	1.60697	$\alpha_{L,4}$	-0.06589	0.324054
$\alpha_{0,30}$	0.68629	1.67595	$\alpha_{L,5}$	-0.19844	0.287238
$\alpha_{0,31}$	3.23662	1.71144	$\alpha_{L,6}$	-0.06644	0.266611
$\alpha_{0,32}$	4.97099	1.73975	$\alpha_{L,7}$	-0.06163	0.279595
$\alpha_{0,33}$	1.41906	1.87904	$\alpha_{L,8}$	0.219847	0.392814
$\alpha_{0,34}$	4.92566	1.62951	$\alpha_{L,9}$	0.377695	0.275679
$\alpha_{0,35}$	-0.1748	2.31137	$\alpha_{L,10}$	0.419143	0.256785
$\alpha_{0,36}$	2.57108	1.65373	$\alpha_{L,11}$	0.165805	0.269847
$\alpha_{0,37}$	2.68888	1.66999	$\alpha_{L,12}$	0.254067	0.280473
			$\alpha_{L,13}$	0.323133	0.291701
β_K	-0.13792	0.188758	$\alpha_{L,14}$	-0.09217	0.243175
$\alpha_{K,1}$			$\alpha_{L,15}$	0.033168	0.254252
$\alpha_{K,2}$	-0.48223	0.175482	$\alpha_{L,16}$	0.182877	0.332996
$\alpha_{K,3}$	-0.21681	0.172512	$\alpha_{L,17}$	0.116462	0.309667
$\alpha_{K,4}$	-0.29212	0.178739	$\alpha_{L,18}$	0.152661	0.27601
$\alpha_{K,5}$	0.524024	0.189992	$\alpha_{L,19}$	-0.40298	0.257467
$\alpha_{K,6}$	-0.1806	0.168562	$\alpha_{L,20}$	0.10033	0.290089
$\alpha_{K,7}$	-0.29378	0.194858	$\alpha_{L,21}$	-0.05878	0.246533
$\alpha_{K,8}$	-0.3274	0.463629	$\alpha_{L,22}$	0.012101	0.266959
$\alpha_{K,9}$	0.013891	0.225846	$\alpha_{L,23}$	0.238059	0.251279
$\alpha_{K,10}$	-0.57332	0.201513	$\alpha_{L,24}$	0.211646	0.285517
$\alpha_{K,11}$	-0.34389	0.184712	$\alpha_{L,25}$	0.232119	0.271288
$\alpha_{K,12}$	-0.23037	0.196765	$\alpha_{L,26}$	-0.01764	0.270478
$\alpha_{K,13}$	-0.03914	0.2488	$\alpha_{L,27}$	-0.04786	0.239775

Table 3. Parameter Estimates of Cost Structure (Sample Period 1981-1996) - Continued

Parameter	Estimate	Standard Error	Parameter	Estimate	Standard Error
$\alpha_{L,28}$	-0.14453	0.318454	$\alpha_{Y,4}$	-0.42131	0.225944
$\alpha_{L,29}$	0.206469	0.266481	$\alpha_{Y,5}$	0.577569	0.215312
$\alpha_{L,30}$	0.170548	0.277321	$\alpha_{Y,6}$	-0.08828	0.188994
$\alpha_{L,31}$	0.067362	0.365111	$\alpha_{Y,7}$	0.071283	0.191973
$\alpha_{L,32}$	0.378274	0.265955	$\alpha_{Y,8}$	-0.01039	0.313918
$\alpha_{L,33}$	0.154204	0.282896	$\alpha_{Y,9}$	-0.2338	0.270028
$\alpha_{L,34}$	0.549666	0.361923	$\alpha_{Y,10}$	0.325122	0.2155
$\alpha_{L,35}$	0.516156	0.406778	$\alpha_{Y,11}$	-0.23438	0.189483
$\alpha_{L,36}$	-0.50552	0.439498	$\alpha_{Y,12}$	-0.19271	0.197137
$\alpha_{L,37}$	0.54435	0.363137	$\alpha_{Y,13}$	0.336623	0.245626
			$\alpha_{Y,14}$	-0.04012	0.206837
β_E	0.076285	0.018176	$\alpha_{Y,15}$	0.041399	0.209288
$\alpha_{E,1}$			$\alpha_{Y,16}$	-0.14175	0.23685
$\alpha_{E,2}$	0.021359	7.72E-03	$\alpha_{Y,17}$	-0.02258	0.21998
$\alpha_{E,3}$	-0.01286	7.45E-03	$\alpha_{Y,18}$	-0.05748	0.201745
$\alpha_{E,4}$	0.01528	7.57E-03	$\alpha_{Y,19}$	0.212148	0.203255
$\alpha_{E,5}$	-0.03556	7.67E-03	$\alpha_{Y,20}$	-0.2662	0.302603
$\alpha_{E,6}$	0.026359	7.53E-03	$\alpha_{Y,21}$	-0.03067	0.202297
$\alpha_{E,7}$	-0.01064	7.80E-03	$\alpha_{Y,22}$	-0.1445	0.214563
$\alpha_{E,8}$	-0.04435	7.63E-03	$\alpha_{Y,23}$	0.034422	0.187276
$\alpha_{E,9}$	-0.0402	7.52E-03	$\alpha_{Y,24}$	-0.21407	0.208113
$\alpha_{E,10}$	-0.04314	7.86E-03	$\alpha_{Y,25}$	-0.33133	0.21013
$\alpha_{E,11}$	-0.03571	7.69E-03	$\alpha_{Y,26}$	0.181484	0.209717
$\alpha_{E,12}$	-0.03449	8.01E-03	$\alpha_{Y,27}$	-0.11886	0.375543
$\alpha_{E,13}$	-0.05312	7.73E-03	$\alpha_{Y,28}$	0.033681	0.236817
$\alpha_{E,14}$	-0.03205	7.56E-03	$\alpha_{Y,29}$	0.06145	0.210291
$\alpha_{E,15}$	-0.04082	7.56E-03	$\alpha_{Y,30}$	0.152294	0.211514
$\alpha_{E,16}$	-0.05191	7.66E-03	$\alpha_{Y,31}$	-0.02587	0.327246
$\alpha_{E,17}$	-0.02588	7.86E-03	$\alpha_{Y,32}$	-1.30088	0.250253
$\alpha_{E,18}$	-0.04681	7.72E-03	$\alpha_{Y,33}$	-0.28925	0.242029
$\alpha_{E,19}$	0.013567	7.92E-03	$\alpha_{Y,34}$	-0.5157	0.203595
$\alpha_{E,20}$	-0.04913	7.90E-03	$\alpha_{Y,35}$	-0.18175	0.28968
$\alpha_{E,21}$	0.019871	7.65E-03	$\alpha_{Y,36}$	9.02E-03	0.267514
$\alpha_{E,22}$	-0.04401	7.52E-03	$\alpha_{Y,37}$	-0.24469	0.232764
$\alpha_{E,23}$	-0.05048	7.63E-03			
$\alpha_{E,24}$	-0.04214	7.84E-03	β_B	-0.24357	0.349497
$\alpha_{E,25}$	-0.05461	8.22E-03	$\alpha_{B,1}$		
$\alpha_{E,26}$	1.14E-03	7.47E-03	$\alpha_{B,2}$	0.22919	0.091914
$\alpha_{E,27}$	-0.02463	7.68E-03	$\alpha_{B,3}$	-0.04362	0.082894
$\alpha_{E,28}$	9.53E-03	7.74E-03	$\alpha_{B,4}$	0.71505	0.156504
$\alpha_{E,29}$	-0.04953	7.84E-03	$\alpha_{B,5}$	-1.92779	0.126386
$\alpha_{E,30}$	-0.04157	7.86E-03	$\alpha_{B,6}$	-0.12439	0.081974
$\alpha_{E,31}$	0.0548	7.81E-03	$\alpha_{B,7}$	0.031471	0.089945
$\alpha_{E,32}$	-6.36E-03	8.42E-03	$\alpha_{B,8}$	-0.0389	0.150138
$\alpha_{E,33}$	-0.0176	7.68E-03	$\alpha_{B,9}$	-0.03232	0.13163
$\alpha_{E,34}$	-0.03765	8.00E-03	$\alpha_{B,10}$	-0.02241	0.099737
$\alpha_{E,35}$	0.017356	8.12E-03	$\alpha_{B,11}$	-1.41E-03	0.089924
$\alpha_{E,36}$	-0.01819	7.93E-03	$\alpha_{B,12}$	-0.01937	0.109947
$\alpha_{E,37}$	-0.01638	7.87E-03	$\alpha_{B,13}$	5.48E-03	0.106752
			$\alpha_{B,14}$	-0.02948	0.087042
β_Y	-1.9234	0.698464	$\alpha_{B,15}$	-1.73E-03	0.086581
$\alpha_{Y,1}$			$\alpha_{B,16}$	0.021641	0.098459
$\alpha_{Y,2}$	-0.1233	0.202763	$\alpha_{B,17}$	0.168601	0.101881
$\alpha_{Y,3}$	-2.61E-03	0.203294	$\alpha_{B,18}$	1.46E-03	0.092735

Table 3. Parameter Estimates of Cost Structure (Sample Period 1981-1996) - Continued

Parameter	Estimate	Standard Error	Parameter	Estimate	Standard Error
$\alpha_{B,19}$	-0.10597	0.111986	β_t	0.042821	0.017031
$\alpha_{B,20}$	0.040838	0.140766	β_{KK}	-0.02496	7.10E-03
$\alpha_{B,21}$	9.37E-03	0.172539	β_{LL}	0.033634	3.96E-03
$\alpha_{B,22}$	0.018946	0.11355	β_{EE}	0.018073	1.26E-03
$\alpha_{B,23}$	0.070726	0.107867	β_{YY}	0.233183	0.087873
$\alpha_{B,24}$	2.92E-03	0.131835	β_{BB}	6.74E-03	0.032173
$\alpha_{B,25}$	0.023261	0.090364	β_{tt}	-2.94E-04	1.46E-04
$\alpha_{B,26}$	0.015604	0.15398			
$\alpha_{B,27}$	-0.05369	0.141198	β_{EK}	6.24E-03	2.71E-03
$\alpha_{B,28}$	-0.1261	0.152542	β_{EL}	-7.68E-03	3.13E-03
$\alpha_{B,29}$	-9.45E-03	0.085635	β_{EY}	-0.0164	2.88E-03
$\alpha_{B,30}$	-0.07449	0.128129	β_{EB}	4.47E-03	1.39E-03
$\alpha_{B,31}$	-0.0695	0.235423	β_{ET}	1.58E-04	2.23E-04
$\alpha_{B,32}$	0.106971	0.103081	β_{KL}	0.031343	6.91E-03
$\alpha_{B,33}$	-0.02328	0.084992	β_{KY}	0.162921	0.014872
$\alpha_{B,34}$	0.016713	0.095885	β_{KB}	-0.01553	7.15E-03
$\alpha_{B,35}$	0.156925	0.138511	β_{Kt}	-2.83E-03	1.24E-03
$\alpha_{B,36}$	-0.11913	0.144599	β_{LY}	-0.11251	7.49E-03
$\alpha_{B,37}$	0.071887	0.140659	β_{LB}	1.39E-03	3.61E-03
			β_{Lt}	-5.61E-04	5.91E-04
ρ	0.2096	0.040871	β_{YB}	0.036789	0.083814
ρ_E	0.810904	0.024865	β_{Yt}	-5.14E-03	4.77E-03
ρ_K	1.00025	4.02E-03	β_{Bt}	3.09E-03	2.99E-03
ρ_L	1.00166	1.46E-03			

Table 3. Parameter Estimates of Industries' Cost Structure (Sample Period 1996-1998)—Continued

Equation	Standard Error	R^2
Total Cost	0.027976	0.98
Capital Share	0.025634	0.98
Labour Share	0.012446	0.99
Energy Share	0.004354	0.98

Table 4. Hypothesis Testing

Parameter Restrictions	Log of Likelihood	χ^2	Degrees of Freedom
$\underline{\alpha}_{oh} = \underline{\alpha}_{Kh} = \underline{\alpha}_{Lh} = \underline{\alpha}_{Eh} = \underline{\alpha}_{Yh} = \underline{\alpha}_{Bh} = \underline{\alpha}_{th} = \underline{\alpha}_{i,j,h} = \underline{\alpha}_{i,Y,h} = \underline{\alpha}_{i,B,h} = \underline{\alpha}_{i,t,h} = 0$	1941	1239	407
$\underline{\alpha}_{B,h} = \underline{\alpha}_{i,B,h} = 0$	1863	712	64

Note: The critical values χ^2 with 407 and 64 degrees of freedom are 654 and 126, respectively.

$\underline{\alpha}$ is the vector of dummy parameters.

2. *Various Estimation Issues*

A) Spurious Correlation

The presence of common trend among variables in the time series models of production structure is a serious econometric issue. This criticism is equally applicable to production and cost function studies, whether they include environmental variables or not. It is true that private sector variables such as output, labour, intermediate inputs and private capital stock are highly correlated over time and may share a common trend. There is nothing particularly different about environmental variables in this respect.

One method for removing a common trend is to estimate the model in a first-difference form. Estimation of this form eliminates a potential influence of trend. Equations (5) and (6) were estimated in 'first-difference' form by setting the serial correlation parameter ρ to unity. The parameter estimates (not reported here, but available on request) indicate that the models fit the data very well. Signs and magnitudes are similar to those when the models were estimated in level form. This should not come as a surprise as the values of the serial correlation coefficients ρ shown in Table 3 are close to unity.

B) The Issue of Capital Fixity

The various cost and demand relationships developed above are characterized through first and second order derivatives or elasticities of the cost function with respect to the arguments of $G(\cdot)$. However, divergence in input demand patterns from those appropriately represented by Shephard's lemma would complicate or preclude the estimation and interpretation of these elasticities. Even though such deviations from standard assumptions of basic microeconomic theory did not emerge in the end, the knowledge that they might exist stimulated an empirical investigation of alternative models that recognizes these potential difficulties.

The most common problem of this sort is the quasi-fixity of inputs such as capital. If full adjustment to equilibrium input levels does not take place within the time frame of the data, Shephard's lemma will not appropriately represent input demand behavior. This rigidity problem is often dealt with by incorporating capital stock instead of its rental price in the $G(\cdot)$ function if we have reasons to believe that capital has binding fixity constraints. This implied divergence from equilibrium demand (or, equivalently, variations from full utilization) represented by the deviations between a factor's shadow value $z_K = -\frac{\partial G}{\partial K}$ and its market price w_K.

Alternatively, the true/effective quantity demand of an input may be represented by directly adapting the *data* to embody the discrepancy. In particular, if the true (or shadow) price of the factor z_K is used as an argument of $G(\cdot)$ rather than an unadjusted market price, the validity of Shephard's lemma is maintained.

Although the data for this study were carefully constructed to reflect the input flow values, sensitivity checks were carried out to determine the validity of the assumption of variable inputs. These checks supported our final empirical specification; the assumption seemed justified by the appropriate levels and shapes of the resulting demand equations. In fact, when capital was not characterized as a choice variable, the results were not as justifiable as when Shephard's lemma was implemented.

Our empirical findings based on these data suggest that the approach employed was carried out in a manner consistent with economic theory. The use of Shephard's lemma seems justified by both the correct (in terms of required regularity conditions) and intuitively plausible estimates of demand behavior. And when optimization equations were not imposed for the K input, the resulting estimates remained substantively unchanged.

3. Economic Interpretation

The various cost elasticities computed from the estimated parameters for the full data sample are presented in Table 5. The reported estimates are weighted averages across all the 37 industries and time periods for each measure. The t-statistics are based on computation of the measures evaluated at the average (mean) values of the data.[3]

The primary measures for evaluating the marginal benefit of using the environment for disposal of greenhouse gases is the shadow value s_B computed by partial differentiation of (5) with respect to ℓnB. At the aggregate level, the cost elasticity of the bad output $\varepsilon_{G,B}$ is -0.14, thus indicating that allowing higher emissions is cost-saving for the producer. The significance level is better than 2 percent. There is however a great deal of variation across industries. With a value of -1.91, the oil and gas industry shows the highest cost elasticity with respect to emissions, followed far behind by chemical industries with -0.12.

The negative aggregate estimate of $\varepsilon_{K,B}$ suggests that capital has a tendency to "substitute" for environmental quality, in the sense that additional capital is required to reduce emissions. Both of the elasticities of labour and energy with respect to emissions are positive, but only the latter is statistically significant. Reduction of emissions implies lower energy use.

For the outputs, the positive elasticity $(\varepsilon_{MC_Y B} = 0.037)$ implies the absence of scope economies or jointness between the good and bad output. However, this result is not statistically significant. Some interesting implications are suggested by the emission shadow value in Table 5. The results indicate that the shadow value of emissions increases at 0.03 percent per year on average, holding other variables constant.

[3] The measures were constructed for these data using the delta method (essentially a generalized Wald test) by the ANALYZ command in TSP.

Table 5. Estimates of the Elasticities (Mean Values 1981-1996)

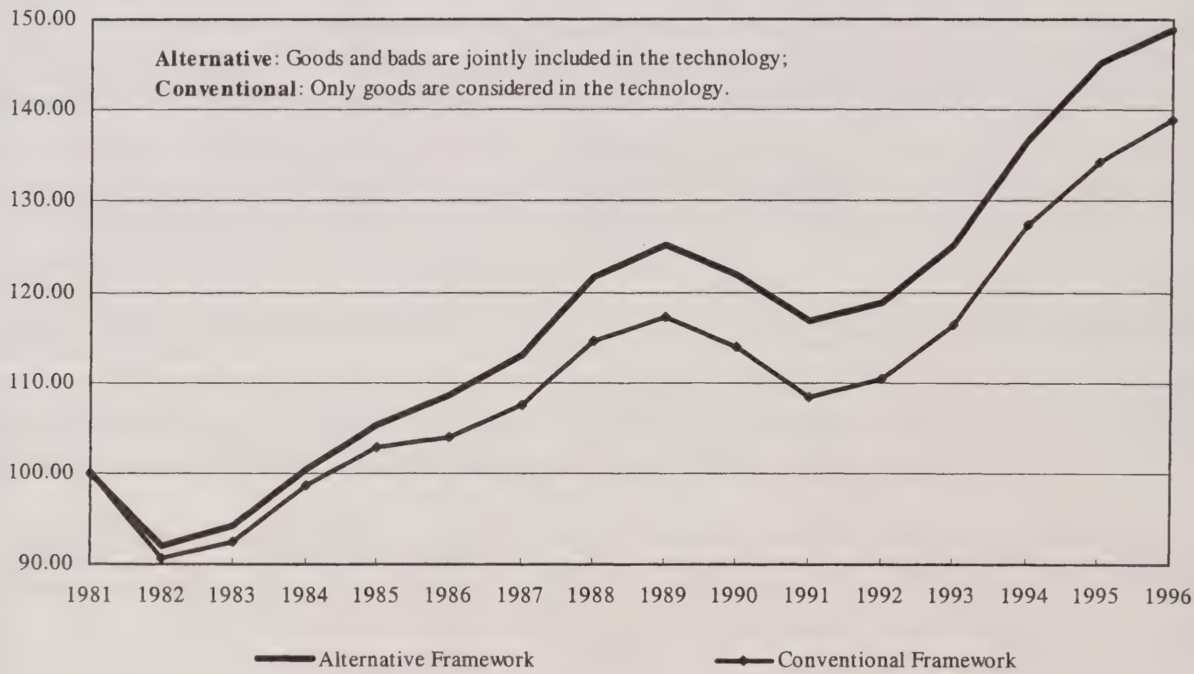
Industries	$\varepsilon_{G,B}$	$\varepsilon_{G,Y}$	$\varepsilon_{G,K}$	$\varepsilon_{G,L}$	$\varepsilon_{G,E}$	$\varepsilon_{G,t}$	$\varepsilon_{K,B}$	$\varepsilon_{L,B}$	$\varepsilon_{E,B}$	$\varepsilon_{Sb,t}$	OSE	ESC
Agricultural and related services	0.0137	0.9728 **	0.2752 **	-0.0281	0.0522 **	0.0036 **	-0.0155**	0.0014	0.0045 **	0.2249	0.9865**	0.0004
Fishing and trapping	0.2417 **	0.8147 **	-0.1995 *	0.3574 **	0.0658 **	0.0034 **	-0.0155**	0.0014	0.0045 **	0.0128	1.0565**	0.0005
Logging and forestry	-0.0229	1.0076 **	0.0713 *	0.7955 **	0.031 **	0.0043 **	-0.0155**	0.0014	0.0045 **	-0.1349	0.9848**	0.0003
Mining	0.7207 **	0.5918 **	-0.0407	-0.0834	0.0689 **	0.0026 **	-0.0155**	0.0014	0.0045 **	0.0043	1.3125**	0.0004
Crude petroleum and natural gas	-1.9087**	1.7075 **	0.796 **	-0.2272	0.02 **	0.003 **	-0.0155**	0.0014	0.0045 **	-0.0016	-0.2012	0.0002
Quarry and sand pit	-0.1144**	0.9567 **	0.0946 **	-0.0951	0.0738 **	0.0021 *	-0.0155**	0.0014	0.0045 **	-0.027	0.8424**	0.0005
Services incidental to mineral extraction	0.0241	1.0153 **	-0.0793	-0.0523	0.0449 **	0.0024 **	-0.0155**	0.0014	0.0045 **	0.1283	1.0394**	0.0005
Food	-0.0334	1.0049 **	-0.0821	0.2132 **	0.0137 **	0.0027 **	-0.0155**	0.0014	0.0045 **	-0.0926	0.9715**	0.0004
Beverage	-0.0308	0.7305 **	0.2614 **	0.3707 **	0.0133 **	0.0024 **	-0.0155**	0.0014	0.0045 **	-0.1001	0.6997**	0.0006
Tobacco	-0.0288	1.1418 **	-0.361 **	0.4484 **	0.0128 **	0.004 **	-0.0155**	0.0014	0.0045 **	-0.1071	1.113 **	0.0006
Rubber products	0.003	0.8123 **	-0.0866	0.1536 **	0.0209 **	0.0015	-0.0155**	0.0014	0.0045 **	1.0156	0.8154**	0.0005
Plastic products	-0.003	1.0119 **	0.0502	0.2172 **	0.0222 **	0.0012	-0.0155**	0.0014	0.0045 **	-1.034	1.009 **	0.0003
Leather and allied products	-0.0056	1.1328 **	0.1504	0.347 **	0.0082 **	0.0044 **	-0.0155**	0.0014	0.0045 **	-0.5559	1.1272**	0.0005
Primary textile	-0.0309	0.8598 **	-0.0647	-0.0833**	0.0273 **	0.0025 **	-0.0155**	0.0014	0.0045 **	-0.1	0.8289**	0.0006
Textile products	0.0104	1.0568 **	-0.111 **	0.0197	0.0174 **	0.0039 **	-0.0155**	0.0014	0.0045 **	0.2964	1.0672**	0.0003
Clothing	0.0224	0.838 **	-0.1145**	0.1736 *	0.0069 **	0.0024 **	-0.0155**	0.0014	0.0045 **	0.1378	0.8604**	0.0005
Wood	0.1873 **	1.0624 **	-0.1146**	0.0698	0.0252 **	0.0024 **	-0.015 **	0.0014	0.0045 **	0.0165	1.2497**	0.0004
Furniture and fixture	0.0089	0.9999 **	0.0904	0.1347 **	0.0121 **	0.0032 **	-0.0155**	0.0014	0.0045 **	0.346	1.0089 *	0.0003
Paper and allied products	-0.1047	1.2892 **	0.1033	-0.4068**	0.0708 **	0.0012	-0.0155**	0.0014	0.0045 **	-0.0295	1.1845**	0.0004
Printing and publishing	0.0483	0.8279 **	0.2317 **	0.0896	0.0085 **	0.003 **	-0.0155 *	0.0014	0.0045 **	0.064	0.8761**	0.0003
Primary metal	0.0133	0.9724 **	-0.1333 *	-0.0556 *	0.0725 **	0.0023 **	-0.0155**	0.0014	0.0045 **	0.2324	0.9857**	0.0004
Fabricated metal products	0.0271	0.8283 **	0.005	-0.0003	0.0145 **	0.0039 **	-0.0155**	0.0014	0.0045 **	0.1138	0.8554**	0.0003
Machinery	0.0715 **	0.9794 **	-0.0616 *	0.2377 **	0.009 **	0.0037 **	-0.0155**	0.0014	0.0045 **	0.0432	1.0509**	0.0004
Transportation equipment	0.0256	1.0025 **	-0.1787 *	0.1588 *	0.0088 **	0.0013	-0.0155**	0.0014	0.0045 **	0.1208	1.028 **	0.0003
Electrical and electronic equipment	0.0346	0.8719 **	0.1093	0.2014 **	0.0007	-0.0008	-0.0155**	0.0014	0.0045 **	0.0894	0.9065**	0.0005
Non-metallic mineral products	0.0236	1.1043 **	0.0772 **	-0.0339	0.0545 **	0.0043 **	-0.0155**	0.0014	0.0045 **	0.1311	1.1279**	0.0004
Refined petroleum products	-0.0528	0.7688 **	0.015	-0.0184	0.0339 **	0.004 **	-0.0155**	0.0014	0.0045 **	-0.0584	0.7159 **	0.0004
Chemical industries	-0.1177**	1.1108 **	-0.2255 *	-0.1589**	0.0617 **	0.0022 **	-0.0155**	0.0014	0.0045 **	-0.0262	0.9931 **	0.0004
Other manufacturing	-0.0075	1.103 **	-0.0378	0.2024 **	0.0103 **	0.0022 **	-0.0155**	0.0014	0.0045 **	-0.41	1.0955 **	0.0004
Construction	-0.0753**	1.1911 **	-0.0062	0.1588 **	0.0115 **	0.0024 **	-0.0155**	0.0014	0.0045 **	-0.041	1.1158 **	0.0004
Transportation industries	-0.0599	1.061 **	-0.353 **	0.0417	0.103 **	0.0028 **	-0.0155**	0.0014	0.0045 **	-0.0515	1.0011 **	0.0003
Pipeline transport	0.1259	-0.1095	0.4059 **	0.3446 **	0.0475 **	0.0021	-0.0155**	0.0014	0.0045 **	0.0245	0.0164	0.0002
Storage and warehousing	-0.0165	0.7713 **	0.2385 **	0.1322	0.0339 **	0.0031 **	-0.0155**	0.0014	0.0045 **	-0.1875	0.7548 **	0.0003
Communication	0.0344 *	0.6909 **	-0.2756**	0.4994 **	0.0109 **	0.0019	-0.0155**	0.0014	0.0045 **	0.0899	0.7253 **	0.0002
Other utility	0.168 **	0.9409 **	0.3237 *	0.4955 **	0.0623 **	0.0025 **	-0.0155**	0.0014	0.0045 **	0.0184	1.1089 **	0.0004
Wholesale trade	-0.1052**	1.1828 **	-0.1674 *	-0.5448 *	0.0292 **	0.0013	-0.0155**	0.0014	0.0045 **	-0.0294	1.0776 **	0.0003
Retail Trade	0.0798**	0.8716**	-0.1516**	0.512**	0.0359**	0.002*	-0.0155**	0.0014	0.0045 **	0.0387	0.9514**	0.0004
Total (37 Industries)	-0.1386**	1.0222 **	0.0956 **	0.1065 **	0.0564 **	0.0023 **	-0.0155**	0.0014	0.0045 **	0.0281	0.9618 **	0.0003

Note: * and ** mean statistically significant at 5 and 10 percent, respectively.

It is also informative to compare some of the elasticity estimates across time periods and industries. We report measures separated into pre- and post-1990s, in an attempt to identify a possible break in public awareness or institutional pressure with regard to the effects of greenhouse gases. If anything, the $\varepsilon_{G,B}$ value for the pre- and post-1990s show a slight reduction in the proportional cost savings of B disposal: $\varepsilon_{G,B} = -0.1504; -0.1208$, respectively.

The estimates of multifactor productivity growth rates require estimates of ray scale economies, aggregated good and bad outputs and technical change. The required cost elasticities are taken from the parameter estimates of the translog cost function discussed earlier. Figure 2 presents the multifactor productivity indices for the period 1981-1996 for the 37 industries considered in our empirical analysis. The estimates used in figure 1 are weighted averages of all industries in the sample. In other words, multifactor productivity indices for each industry were estimated and the weighted average of these estimates is presented in Figure 2. The standard framework that excludes bad output underestimates productivity growth by almost 0.5 percentage points per year over the 1981-1996 period.[4]

Figure 2: Multifactor Productivity Compounded Growth Rate Under Alternate Production Frameworks: Business Sector



[4] Under the constant returns to scale assumption that is consistent with the growth accounting framework, the exclusion of greenhouse gases emissions leads to an under estimation of 0.2 percentage points (see Harchaoui *et al* 2002).

V. Concluding Remarks

To a remarkable extent, environmental protection is generally perceived in the public debate as imposing costly burdens on the economy, stifling innovation and lowering productivity. However, the conclusion that environmental protection generally leads to lower productivity performance is in fact an artifact in the way the productivity measure is implemented—a methodology that counts only the cost of environmental protection but ignores the production of a better environment, say in terms of emissions reduction.

For many years, many studies hampered by this methodological shortcoming, concluded that in general environmental protection leads to a decline in the productivity performance. However, a recent strand of the economic literature, to which this paper belongs, recognizes that some outputs are valuable when sold and others are damaging when released (see Murtough *et al.* 2001 for a review of this literature). When the productivity framework considers an industrial process in its entirety, environmental protection is no longer seen to necessarily hamper productivity performance.

This study uses a detailed model of the production structure in the Canadian business sector to measure the private costs that producers have incurred in the past two decades as they reduced greenhouse gas emissions. We find the private implicit or shadow value of emissions to be significant, larger for the mining sector and increasing in magnitude over time. Firms do not choose their production and output mix as if the environment was free and valueless. This means that firms incur, or perceive, costs from GHG emissions, beyond their private input bill. These costs may have resulted from regulatory pressure or from public opinion, or from anticipations of future regulatory or public pressure.

Failing to account for greenhouse gas emissions generally leads to an underestimate of productivity growth. Cost changes associated with emission reductions are interpreted as productivity losses in conventional measures. We have computed a multifactor productivity index that includes emissions as input. That index grows faster by half a percentage point a year over the 1981-1996 period than the conventional index.

In conclusion, we have shown that the methodology used in this paper has the major advantage that it can readily incorporate unpriced environmental impacts into productivity growth estimates. A disadvantage is that the methodology is data intensive and technically challenging. The value of the new productivity estimate that the experimental approach produces depends on the shadow price of CO_2 emissions. Because it is derived from a multivariate statistical analyses, there is an inherent uncertainty in the accuracy of the shadow price. It should be recognized that the results of these analyses are therefore subject to error. The size of the error will depend on the accuracy of the functional forms used, the type of econometric analysis employed and the accuracy of the data that are utilized.

Nevertheless, the approach utilized in this study can provide useful insights into how estimated productivity growth can be affected by the environmental impacts of economic activity. There may be scope to extend our analysis to incorporate other environmental by-products. This would require, for example, the measurement and consideration of other pollutants.

References

Cline, W.R. 1992. The Economics of Global Warming, Washington, DC.: Institute for International Economics.

Dachraoui, K. and T.M. Harchaoui. 2002. 'Water Use, Shadow Prices and Canadian Business Sector Productivity Performance: An Efficiency Frontier Approach,' in process.

Färe, R. S. and Grosskopf. 1998. 'Shadow Pricing of Good and Bad Commodities,' *American Journal of Agricultural Economics* 80: 584-90.

Färe, R. and S. Grosskopf and S. Yaisawarng. 1993. 'Derivation of Shadow Prices for Undesirable Outputs: A Distance Function Approach,' *Review of Economics and Statistics* 72: 374-80.

Gollop, F. and G. Swinand. 2001. 'Total Resource Productivity: Accounting for Changing Environmental Quality,' in C. Hulten, E. Dean, M. Harper (eds.); *New Directions in Productivity Analysis*, Studies in Income and Wealth, Volume 63.

Gu, W., M. Kaci, J.-P. Maynard and M.-A. Sillamaa. 2002. "*The Changing Composition of the Canadian Workforce and Its Impact on Productivity*", in Baldwin, J.R. and T.M. Harchaoui: *Productivity Growth in Canada*, 2002, Catalogue No. 15-204-XPE. Microeconomic Analysis Division, Statistics Canada. Forthcoming.

Hailu, A. and T.S.Veeman. 2000. 'Environmentally sensitive productivity analysis of the Canadian pulp and paper industry 1959-1994; an input distance function approach', *Journal of Environmental Economics and Management*, vol. 40, pp. 251-274.

Harchaoui, T.M., D. Kabrelyan, and R. Smith. 2002. 'Accounting for Greenhouse Gases in the Standard Productivity Measure.' *Economic Analysis Series No. 7*. Ottawa: Analytical Studies Branch, Statistics Canada.

Murtough, G., D. Appels, A. Martysek and C.AK. Knovell. 2001. Greenhouse Gas Emissions and the Productivity Growth of Electricity Generators, Productivity Commission Staff Research Paper, AusInfo, Canberra.

Nordhaus, W.D. 1994. Managing the Global Commons: The Economics of Climate Change, Cambridge: The MIT Press.

Panel on Policy Implications of Greenhouse Warming 1992. Policy Implications of Greenhouse Warming: Mitigation, Adaptation, and the Science Base, Washington, DC: National Academy Press.

Pittman, R.W. 1983, ‘Multilateral productivity comparisons with undesirable outputs’, *Economic Journal*, vol. 93, pp. 883–891.

Statistics Canada 1997. Econnections: Linking the Environment and the Economy, Concepts, Sources and Methods of the Canadian System of Environmental and Resource Accounts, Catalogue 16-505-GPE.

ECONOMIC ANALYSIS (EA) RESEARCH PAPER SERIES

No. 001 *A Comparison of Canada-U.S. Economic Growth in the Information Age, 1981-2000: The Importance of Investment in Information and Communication Technologies, Philip Armstrong,* ***Tarek M. Harchaoui, Chris Jackson and Faouzi Tarkhani (March 1, 2002)***

No. 002 *Purchasing Power Parity: A Canada/U.S. Exploration,* ***Beiling Yan (May 2002)***

No. 003 *The Trend to Smaller Producers in Manufacturing: A Canada/U.S. Comparison,* ***John Baldwin, Ron S. Jarmin, Jianmin Tang (May 2002)***

No. 004 *Foreign Affiliate Trade Statistics – 1999: How Goods and Services are Delivered in International Markets,* ***Colleen Cardillo (April 2002)***

No. 005 *Regional Manufacturing Employment Volatility in Canada: The Effects of Specialization and Trade,* ***John R. Baldwin and W.Mark Brown*** *(forthcoming)*

No. 006 *Growth History, Knowledge Intensity and Capital Structure in Small Firms,* ***Guy Gellatly, Allan Riding and Stewart Thornhill*** *(forthcoming)*

No. 007 *Accounting for Greenhouse Gases in the Standard Productivity Framework,* ***Tarek Harchaoui, Dmitry Kabrelyan and Rob Smith (November 1, 2002)***

No. 008 *Overcoming Distance, Overcoming Borders: Comparing North American Regional Trade,* ***W.Mark Brown*** *(forthcoming)*

No. 009 *Assessing the Impact of Greenhouse Gas Emissions on Canada's Productivity Growth, 1981-1996: An Expermental Approach,* ***Tarek M. Harchaoui and Pierre Lasserre (November 1, 2002)***